CHAPTER 5

EARTHQUAKES

An earthquake is generally defined as a sudden motion or trembling in the Earth caused by the abrupt release of slowly accumulated strain. The most common types of earthquakes are caused by movements along faults and by volcanic forces, although they can also result from explosions, cavern collapse, and other minor causes not related to slowly accumulated strains.

Earthquakes are common in Wyoming and the probability is high that they will continue to occur in Wyoming in the future. Historically, earthquakes have occurred in every county in Wyoming (Figure 5.1). However, most earthquakes in Wyoming occur in the western third of the state. The first was reported in Yellowstone National Park in 1871. Yellowstone National Park is one of the more seismically active areas in the U.S.

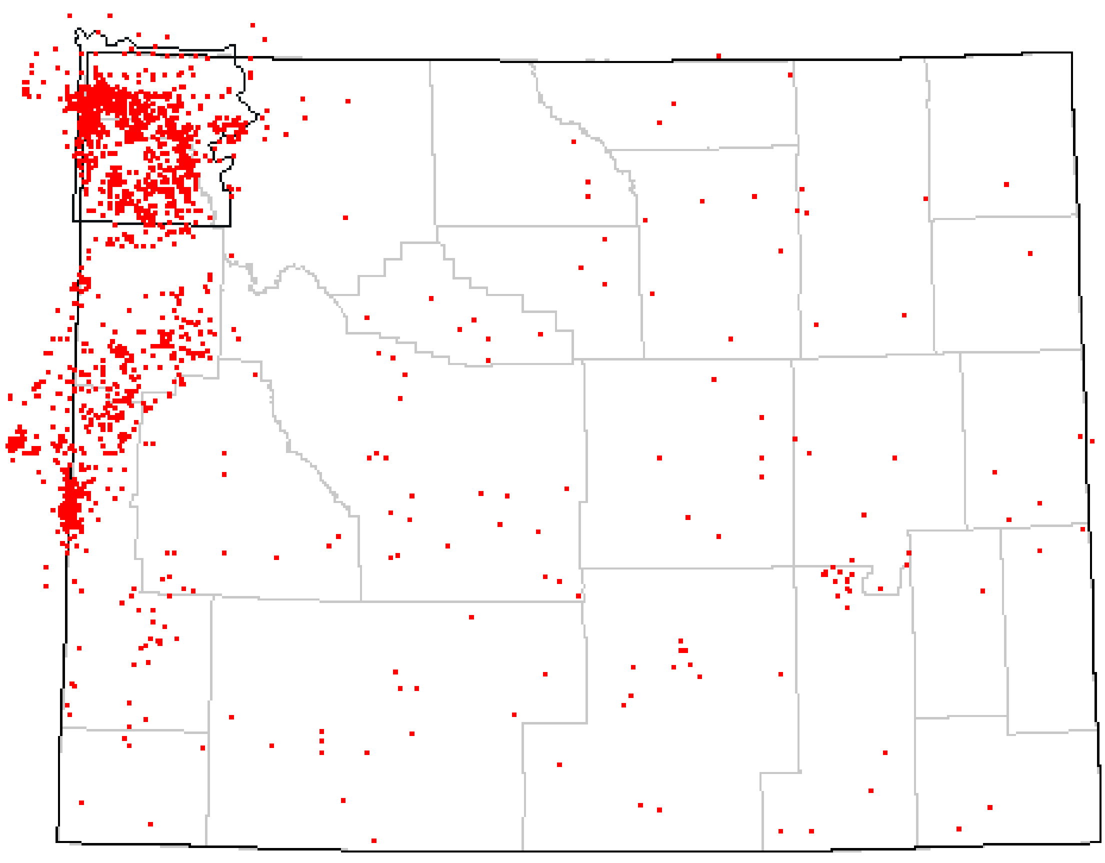

Figure 5.1 Historic Earthquakes in Wyoming

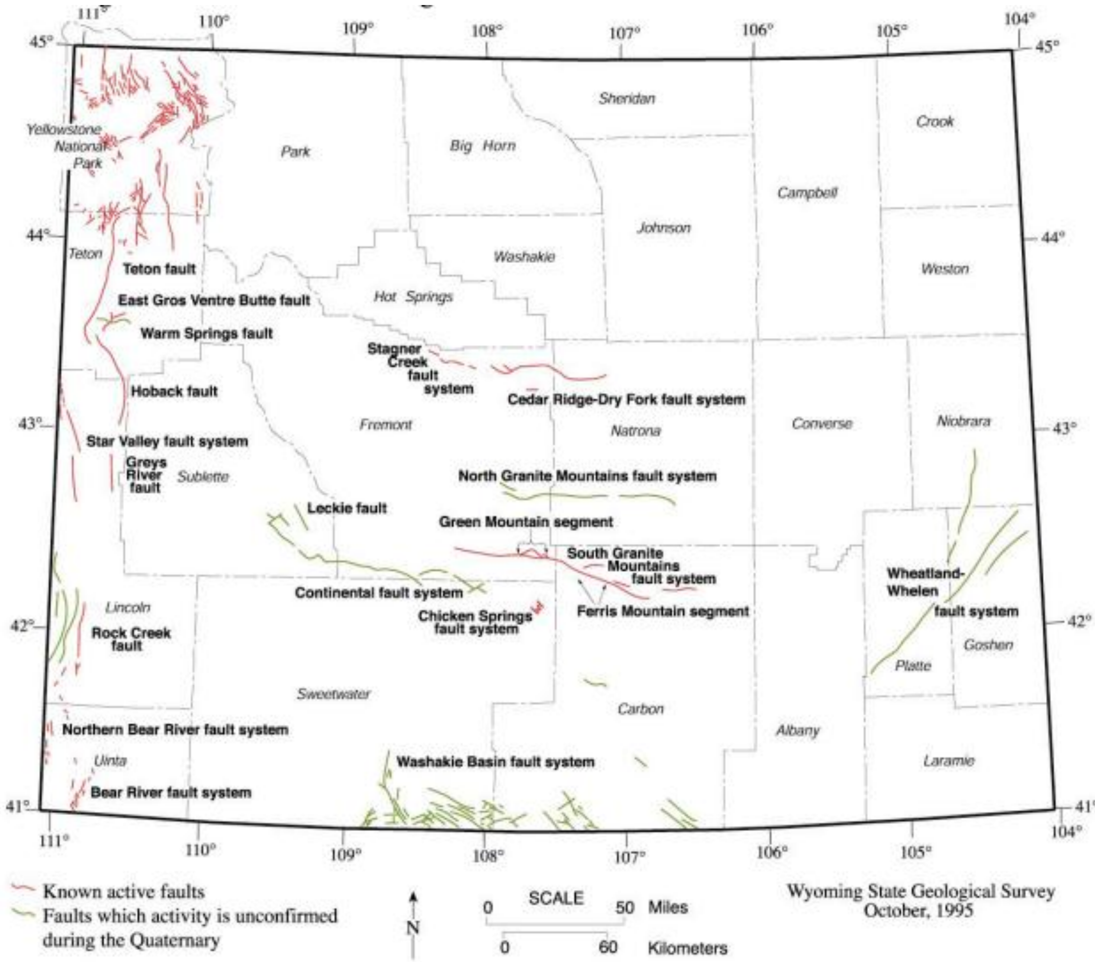

Figure 5.2 Exposed Known or Suspected Active Faults in Wyoming

History

One of the first recorded earthquakes in northeastern Wyoming occurred near Sundance on February 3, 1897. The intensity IV-V earthquake severely shook the Shober School on Little Houston Creek southwest of Sundance. Many residents of Sundance reported hearing three loud reports resembling the explosion of a boiler or a great blast. (Sundance Gazette, February 5, 1897).

On February 18, 1972, a magnitude 4.3 earthquake occurred approximately 18 miles east of Gillette near the Crook County-Campbell County border. No damage was reported.

Deterministic Analysis of Regional Active Faults with a Surficial Expression

There are no known exposed active faults with a surficial expression in Crook County. As a result, no fault-specific analysis can be generated for Crook County.

Floating or Random Earthquake Sources

Many federal regulations require an analysis of the earthquake potential in areas where active faults are not exposed, and where earthquakes are tied to buried faults with no surface expression. Regions with a uniform potential for the occurrence of such earthquakes are called tectonic provinces. Within a tectonic province, earthquakes associated with buried faults are assumed to occur randomly, and as a result can theoretically occur anywhere within that area of uniform earthquake potential. In reality, that random distribution may not be the case, as all earthquakes are associated with specific faults. If all buried faults have not been identified, however, the distribution has to be considered random. “Floating earthquakes” are earthquakes that are considered to occur randomly in a tectonic province.

It is difficult to accurately define tectonic provinces when there is a limited historic earthquake record. When there are no nearby seismic stations that can detect small-magnitude earthquakes, which occur more frequently than larger events, the problem is compounded. Under these conditions, it is common to delineate larger, rather than smaller, tectonic provinces.

The U.S. Geological Survey identified tectonic provinces in a report titled “Probabilistic Estimates of Maximum Acceleration and Velocity in Rock in the Contiguous United States” (Algermissen and others, 1982). In that report, Crook County was classified as being in a tectonic province with a “floating earthquake” maximum magnitude of 6.1. Geomatrix (1988b) suggested using a more extensive regional tectonic province, called the “Wyoming Foreland Structural Province”, which is approximately defined by the Idaho-Wyoming Thrust Belt on the west, 104° West longitude on the east, 40° North latitude on the south, and 45° North latitude on the north. Geomatrix (1988b) estimated that the largest “floating” earthquake in the “Wyoming Foreland Structural Province” would have a magnitude in the 6.0 – 6.5 range, with an average value of magnitude 6.25.

Federal or state regulations usually specify if a “floating earthquake” or tectonic province analysis is required for a facility. Usually, those regulations also specify at what distance a floating earthquake is to be placed from a facility. For example, for uranium mill tailings sites, the Nuclear Regulatory Commission requires that a floating earthquake be placed 15 kilometers from the site. That earthquake is then used to determine what horizontal accelerations may occur at the site. A magnitude 6.25 “floating” earthquake, placed 15 kilometers from any structure in Crook County, would generate horizontal accelerations of approximately 15%g at the site. That acceleration would be adequate for designing a uranium mill tailings site, but may be too large for less critical sites, such as a landfill. Critical facilities, such as dams, usually require a more detailed probabilistic analysis of random earthquakes. Based upon probabilistic analyses of random earthquakes in an area distant from exposed active faults (Geomatrix, 1988b), however, placing a magnitude 6.25 earthquake at 15 kilometers from a site will provide a fairly conservative estimate of design ground accelerations.

Probabilistic Seismic Hazard Analyses

The U.S. Geological Survey (USGS) publishes probabilistic acceleration maps for 500-, 1000-, and 2,500-year time frames. The maps show what accelerations may be met or exceeded in those time frames by expressing the probability that the accelerations will be met or exceeded in a shorter time frame. For example, a 10% probability that acceleration may be met or exceeded in 50 years is roughly equivalent to a 100% probability of exceedance in 500 years.

The USGS has recently generated new probabilistic acceleration maps for Wyoming (Case, 2000). Copies of the 500-year (10% probability of exceedance in 50 years), 1000-year (5% probability of exceedance in 50 years), and 2,500-year (2% probability of exceedance in 50 years) maps are attached. Until recently, the 500-year map was often used for planning purposes for average structures, and was the basis of the most current Uniform Building Code. The new International Building Code, however, uses a 2,500-year map as the basis for building design. The maps reflect current perceptions on seismicity in Wyoming. In many areas of Wyoming, ground accelerations shown on the USGS maps can be increased due to local soil conditions. For example, if fairly soft, saturated sediments are present at the surface, and seismic waves are passed through them, surface ground accelerations will usually be greater than would be experienced if only bedrock was present. In this case, the ground accelerations shown on the USGS maps would underestimate the local hazard, as they are based upon accelerations that would be expected if firm soil or rock were present at the surface. Intensity values can be found in Table 5.1.

Based upon the 500-year map (10% probability of exceedance in 50 years) (Figure 5.3), the estimated peak horizontal acceleration in Crook County ranges from approximately 2%g in the northeastern corner of the county to greater than 4%g in the southwestern corner of the county. These accelerations are roughly comparable to intensity IV earthquakes (1.4%g – 3.9%g) to intensity V earthquakes (3.9%g – 9.2%g). Intensity IV earthquakes cause little damage. Intensity V earthquakes can result in cracked plaster and broken dishes. Sundance would be subjected to an acceleration of approximately 2 - 3%g or intensity IV.

Based upon the 1,000-year map (5% probability of exceedance in 50 years) (Figure 5.4), the estimated peak horizontal acceleration in Crook County ranges from approximately 3%g in the northeastern corner of the county to greater than 7%g in the extreme southwestern corner of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g). Intensity V earthquakes can result in cracked plaster and broken dishes. Sundance would be subjected to an acceleration of approximately 4-5%g or intensity V.

Based upon the 2,500-year map (2% probability of exceedance in 50 years) (Figure 5.5), the estimated peak horizontal acceleration in Crook County ranges from approximately

5%g in the northeastern corner of the county to nearly 14%g in the southwestern corner of the county. These accelerations are roughly comparable to intensity V earthquakes (3.9%g – 9.2%g) to intensity VI earthquakes (9.2%g – 18%g). Intensity V earthquakes can result in cracked plaster and broken dishes. Intensity VI earthquakes can result in fallen plaster and damaged chimneys. Sundance would be subjected to an acceleration of approximately 8%g or intensity V.

As the historic record is limited, it is nearly impossible to determine when a 2,500-year event last occurred in the county. Because of the uncertainty involved, and based upon the fact that the new International Building Code utilizes 2,500-year events for building design, it is suggested that the 2,500-year probabilistic maps be used for Crook County analyses. This conservative approach is in the interest of public safety.

Modified Mercalli Intensity	Acceleration (%g) (PGA)	Perceived Shaking	Potential Damage
I	<0.17	Not felt	None
II	0.17 – 1.4	Weak	None
III	0.17 – 1.4	Weak	None
IV	1.4 – 3.9	Light	None
V	3.9 – 9.2	Moderate	Very Light
VI	9.2 – 18	Strong	Light
VII	18 – 34	Very Strong	Moderate
VIII	34 – 65	Severe	Moderate to Heavy
IX	65 – 124	Violent	Heavy
X	>124	Extreme	Very Heavy
XI	>124	Extreme	Very Heavy
XII	>124	Extreme	Very Heavy

Table 5.1 Modified Mercalli Intensity and peak ground acceleration (PGA) (Wald, et al 1999).

Abridged Modified Mercalli Intensity Scale

Intensity value and description:

I Not felt except by a very few under especially favorable circumstances.

II Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing automobiles may rock slightly. Vibration like passing of truck. Duration estimated.

IV During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing automobiles rocked noticeably.

V Felt by nearly everyone, many awakened. Some dishes, windows, and so on broken; cracked plaster in a few places; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster and damaged chimneys. Damage slight.

VII Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving cars.

VIII Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving cars disturbed.

IX Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed, slopped over banks.

XI Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII Damage total. Waves seen on ground surface. Lines of sight and level distorted. Objects thrown into the air.

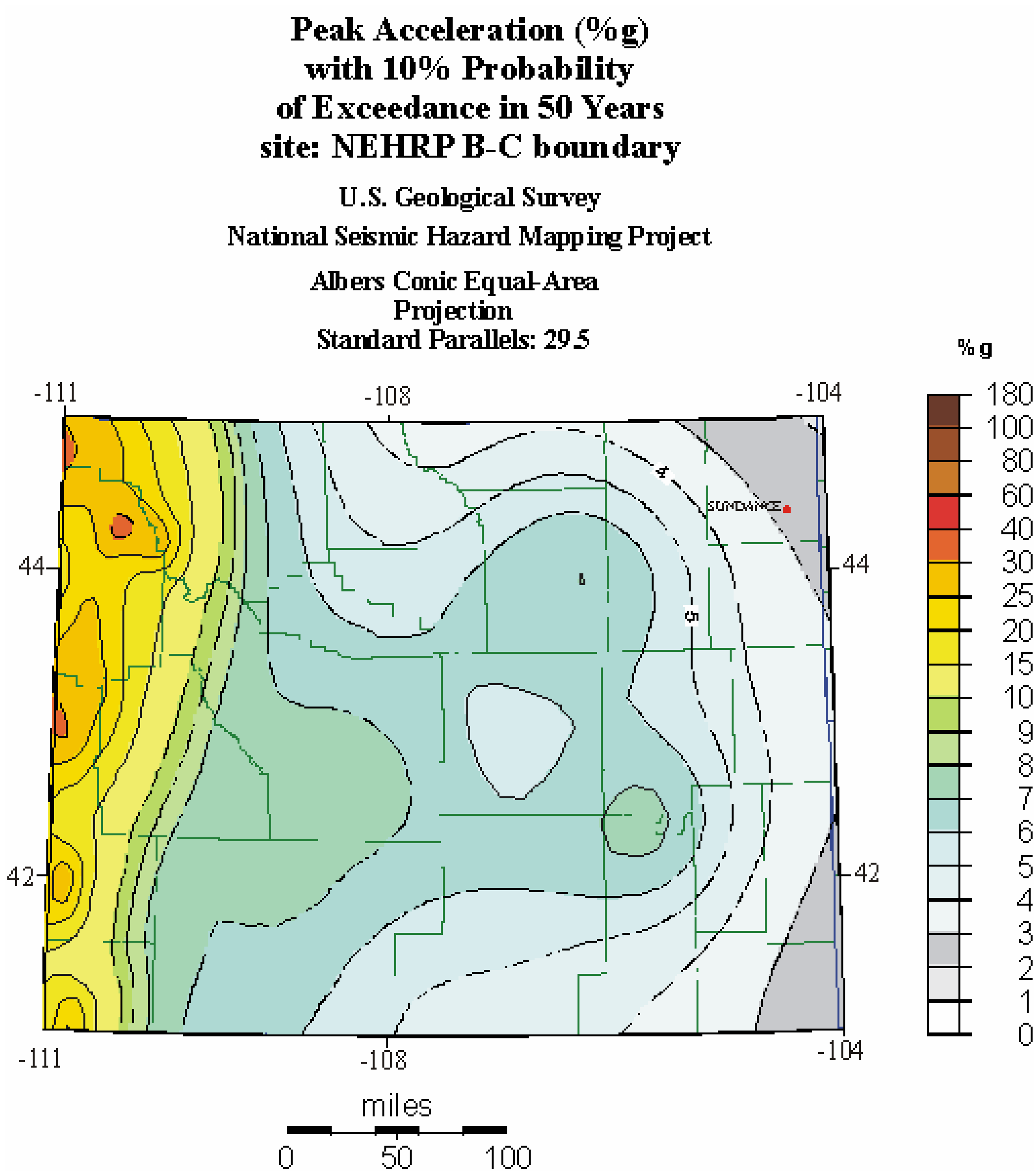

Figure 5.3 500-year probabilistic acceleration map (10% probability of exceedance in 50 years).

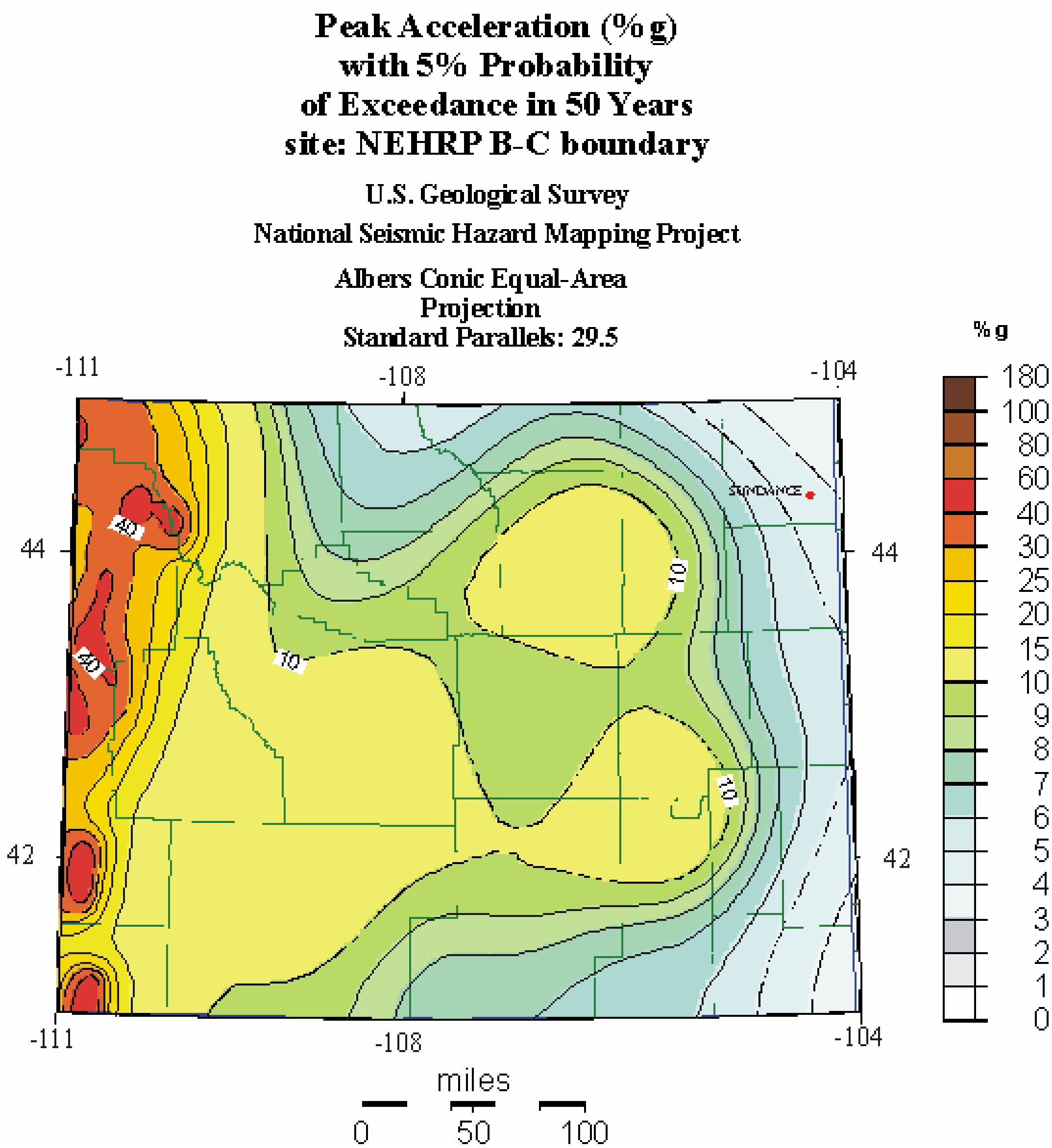

Figure 5.4 1,000-year probabilistic acceleration map (5% probability of exceedance in 50 years).

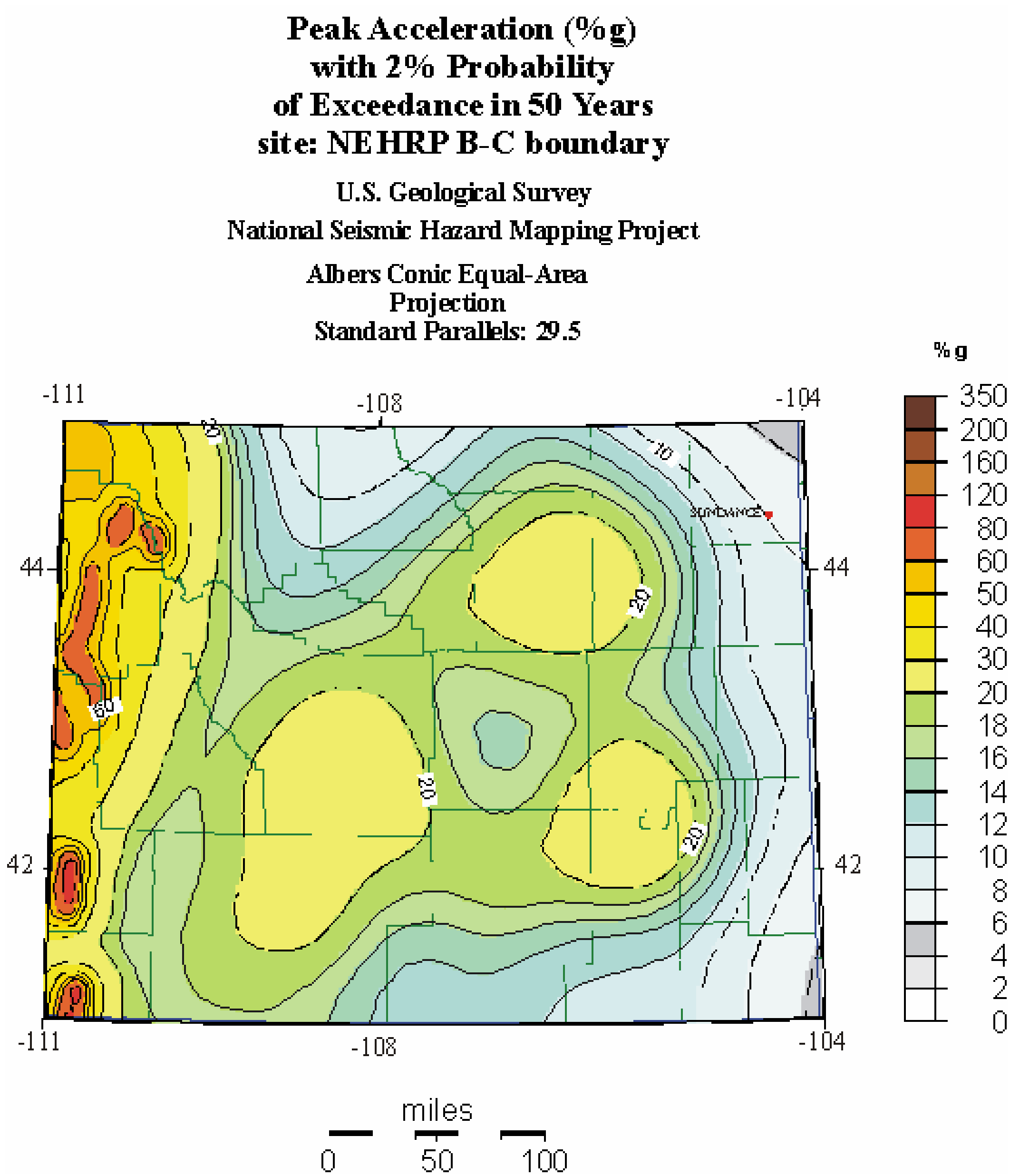

Figure 5.5 2,500-year probabilistic acceleration map (2% probability of exceedance in 50 years).

Impacts

There have been only two historic earthquakes with a magnitude greater than 3.0 recorded in or near Crook County. Because of the limited historic record, it is possible to underestimate the seismic hazard in Crook County if historic earthquakes are used as the sole basis for analysis. Earthquake and ground motion probability maps give a more reasonable estimate of damage potential in areas without exposed active faults at the surface, such as Crook County.

Current earthquake probability maps that are used in the newest building codes suggest a scenario that would result in moderate damage to buildings and their contents, with damage increasing from the northeast to the southwest. More specifically, the probability-based worst-case scenario could result in the following damage at points throughout the county:

<u>Intensity VI Earthquake Areas</u>

- Carlile
- Moorcroft
- Oshoto
- Pine Haven

In intensity VI earthquakes, some heavy furniture can be moved. There may be some instances of fallen plaster and damaged chimneys.

<u>Intensity V Earthquake Areas</u>

- Aladdin
- Alva
- Beulah
- Colony
- Devils Tower
- Hulett
- Moskee
- Sundance

In intensity V earthquakes, dishes and windows can break and plaster can crack. Unstable objects may overturn. Tall objects such as trees and power poles can be disturbed.

Future Impacts

HAZUS (Hazards U.S.) is a nationally standardized, GIS-based, risk assessment and loss estimation computer program that was originally designed in 1997 to provide the user with an estimate of the type, extent, and cost of damages and losses that may occur during and following an earthquake. It was developed for the FEMA by the National Institute of Building Sciences (NIBS). There have been a number of versions of HAZUS generated by FEMA, with HAZUS-MH (HAZUS – Multi-Hazard) being the most recent release. HAZUS-MH incorporates a flood and wind module with the previously existing earthquake module. Hazus-99 (1999 version) was previously used by the Wyoming State Geological Survey (WSGS).

HAZUS was originally designed to generate damage assessments and associated ground motions based largely upon analysis at the census-tract level. Census tracts average 4,000 inhabitants, with the tract boundaries usually representing visible features. HAZUS-99 calculated a ground motion value for the centroid of a census tract, and applied that value to the entire tract. The calculations are based on United States Geological Survey National Seismic Hazard Maps. In many of the western states, census tracts are very large, and parts of the tracts may be subjected to ground shaking that is considerably different than the value at the centroid. FEMA Region VIII and their subcontractor on HAZUS, PBS&J from Atlanta, have worked closely with the Wyoming State Geological Survey (WSGS) to develop a census-block-based analysis for HAZUS-MH in Wyoming. In fact, Wyoming is the national pilot project for the census-block-based analysis. The block-level analysis is a significant improvement. Census blocks are a subdivision of census tracts. Many blocks correspond to individual city blocks bounded by streets, but blocks – especially in rural areas – may include many square miles and may have some boundaries that are not streets. Ground motion values for Wyoming are now calculated at the centroid of census blocks.

As part of the development of the State of Wyoming Multi-Hazard Mitigation Plan a HAZUS probabilistic scenario was run for every Wyoming County. The scenario used a 2,500 year return period, and uses the USGS ground shaking data represented in figure 5.4. The probability of such an event is 2% in 50 years. Crook County used a driving Magnitude of 6.5 associated with the scenario. The results are presented in Tables 5.2 through 5.4

There are two methods of ranking counties to determine where earthquake impacts may be the greatest. Either the loss ratios or total damage figures can be used. The loss ratio is determined by dividing the sum of the structural and non-structural damage by the total building value for the county. The loss ratio is a better measure of impact for a county as it gives an indication of the percent of damage to buildings. The total damage figure by itself does not reflect the percentage of building damage. Loss ratios of 10% or greater can be difficult for a community to recover from. Based on HAZUS, Crook's loss ratio of 1% and overall low total damage loss indicate relatively low earthquake risk.

Table 5.2 HAZUS-MH Summaries for Wyoming Counties										
County	**Capital Stock Losses (Thousands of Dollars)**				**Loss Ratio (%)**	**Income Losses (Thousands of Dollars)**				**Total Loss (Thousands of Dollars)**
	Structural	**Non-structural**	**Contents**	**Inventory**		**Relocation**	**Capital-Related**	**Wages**	**Rental**	**Loss**
Albany	9,714	36,865	13,946	151	2.32	276	2,717	3,198	4,210	71,078
Big Horn	3,470	12,203	4,647	65	2.43	84	533	694	963	22,660
Campbell	5,116	20,093	9,419	282	1.37	144	1,484	2,013	1,592	40,144
Carbon	7,140	26,320	10,480	170	3.08	190	2,120	2,700	1,810	50,920
Converse	6,054	24,172	9,787	185	4.15	152	984	1,303	1,845	44,482
Crook	836	2,640	896	17	1.04	21	107	139	211	4,867
Fremont	14,890	61,030	24,640	460	3.75	380	2,920	3,940	3,190	111,450
Goshen	2,168	6,982	2,543	69	1.13	57	392	528	623	13,364
Hot Springs	3,038	10,871	4,176	52	4.20	82	799	1,149	969	21,136
Johnson	3,293	13,062	5,514	94	3.40	86	557	648	1,066	24,320
Laramie	13,605	47,839	17,577	233	1.25	406	3,926	4,402	4,976	92,963
Lincoln	65,670	225,594	64,429	2,538	31.08	1,211	8,579	10,359	15,347	391,727
Natrona	36,764	137,379	57,269	1,149	3.99	981	9,890	13,033	12,245	268,911
Niobrara	423	1,585	617	12	1.20	12	72	83	132	2,935
Park	11,430	42,694	15,289	429	2.98	285	5,173	6,217	4,487	86,004
Platte	1,875	6,894	2,697	36	1.60	51	326	418	554	12,850
Sheridan	7,830	29,154	12,057	233	2.09	213	1,898	2,402	2,636	56,423
Sublette	9,654	30,667	9,436	222	8.24	206	2,438	3,052	2,665	58,340
Sweetwater	12,782	50,213	20,753	542	2.84	313	2,180	2,514	3,719	93,017
Teton	92,477	359,169	110,323	2,402	24.72	1,821	37,784	43,975	34,030	681,981
Uinta	39,912	135,111	38,841	1,007	15.84	782	5,888	8,741	11,004	241,284
Washakie	4,115	13,761	5,656	134	3.54	99	904	1,019	1,236	26,925
Weston	897	3,016	1,085	21	0.96	26	147	266	302	5,760

Table 5.3 County Impacts Rated by Loss Ratio		
County	**Loss Ratio**	**Total Loss (Thousands of Dollars)**
Lincoln	31.08	391,727
Teton	24.72	681,981
Uinta	15.84	241,284
Sublette	8.24	58,340
Hot Springs	4.20	21,136
Converse	4.15	44,482
Natrona	3.99	268,911
Fremont	3.75	53,860
Washakie	3.54	26,925
Johnson	3.40	24,320
Carbon	3.08	37,762
Park	2.98	86,004
Sweetwater	2.84	93,017
Big Horn	2.43	22,660
Albany	2.32	71,078
Sheridan	2.09	56,423
Platte	1.60	12,850
Campbell	1.37	40,144
Laramie	1.25	92,963
Niobrara	1.20	2,935
Goshen	1.13	13,364
Crook	1.04	4,867
Weston	0.96	5,760

Table 5.4 County Impacts Rated by Dollar Loss		
County	**Total Loss (Thousands of Dollars)**	**Loss Ratio**
Teton	681,981	24.72
Lincoln	391,727	31.08
Natrona	268,911	3.99
Uinta	241,284	15.84
Sweetwater	93,017	2.84
Laramie	92,963	1.25
Park	86,004	2.98
Albany	71,078	2.32
Sublette	58,340	8.24
Sheridan	56,423	2.09
Fremont	53,860	3.75
Converse	44,482	4.15
Campbell	40,144	1.37
Carbon	37,762	3.08
Washakie	26,925	3.54
Johnson	24,320	3.4
Big Horn	22,660	2.43
Hot Springs	21,136	4.2
Goshen	13,364	1.13
Platte	12,850	1.6
Weston	5,760	0.96
Crook	4,867	1.04
Niobrara	2,935	1.2

In summary, it is estimated that if a worse case event occurred in Crook County, $4,867,000 in building related damage could occur. HAZUS estimates that 151 buildings (5% of the total in the County), would be at least moderately damaged. The probability of such an event is 2% in 50 years. In comparison with other Wyoming counties, Crook's earthquake risk is low.

Summary

PROPERTY AFFECTED: Low
POPULATION AFFECTED: Medium
PROBABILITY: Low
JURISDICTION AFFECTED: County